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Variation in Shot Impacts Due to Controlled Bending of a Gun Tube

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13. ABSTRACT *(Maximum 200 words)*

It is possible that a given lot of ammunition fired at the same aim point by two different tanks will produce center of (shot) impacts, COIs, that differ in magnitude by several times the lot's dispersion. It is difficult to discern what fraction of this variation is due to barrel differences, alone, since changing tubes alters both the mounting conditions and the occasion. A means has been devised to "change tubes" without altering the mount, or the occasion, by merely changing the shape of a given tube within the same mount. This is accomplished by localized control of the barrel's axial thermal expansion, implemented through a series of temperature-controlled heating pads adhered to the outer barrel wall. Using this technique, it was found that a simple, yet very common, bow-shaped curvature to the right vs. left, for example, produced a significant shift in the COI, the magnitude of which was on the order of the ammunition dispersion. In particular, inducing a right bow moved the muzzle to the left, as expected, but had the opposite, and perhaps unexpected, effect on the shot impacts--moving them to the right. Conversely, forming a left bow moved the muzzle to the right and the shot impacts to the left.

An attempt to gain an understanding of the observed COI-centerline dependence through modeling the effects of projectile-barrel interaction (using the gun dynamics code Rascal) did not succeed. It appears that a more comprehensive model is needed before a predicative capability is possible.

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1. INTRODUCTION

The difference between the gravity-, wind-, and drag-corrected aim point and where a projectile actually hits the target is referred to as projectile jump. Projectile jump varies from round to round, but, in general, roughly two-thirds of the rounds will hit the target within one standard deviation (defined as the ammunition dispersion) of the center of (shot) impacts, COIs, for a given lot of ammunition. However, the COI will vary from tube to tube, mount to mount, and occasion to occasion. In a test with early production 120-mm M256 tubes (Walbert and Petty 1985), the COIs from six different tank-tube combinations were found to vary by 3 mils (roughly 3 m at 1,000 m) in azimuth and elevation. It is likely that production M256 tubes today would show a smaller variation, maybe half (Webb 1996), nonetheless, a large source of error.

It is difficult to discern what fraction of this variation is due to barrel differences alone, since changing tubes alters both the mounting conditions and the occasion. Some indication of barrel dependence was given in the "rotated tube" test of Haug, Petty, and Walbert (1988). They rotated a (preproduction) 120-mm M256 barrel (ser. no. 84) through 90° increments and recorded the COI for 10-round groups at each orientation, Figure 1.

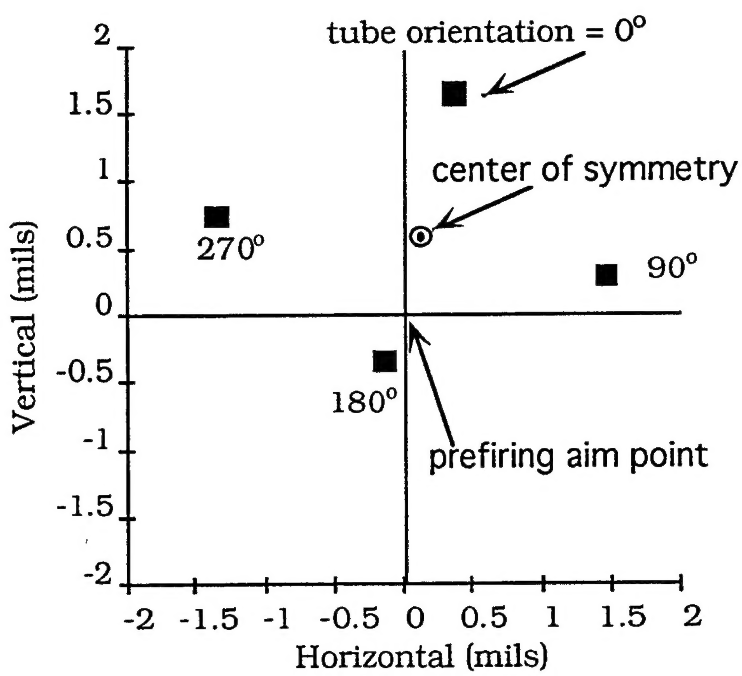

Figure 1. Centers of impact for 10-round groups fired through M256 (ser. no. 84) in rotated tube test.

Each rotation of the barrel in the test of Figure 1 required the equivalent of a mount change, necessitating at least 1 day between firings. In spite of the mount and occasion changes, it is quite obvious from the test results that the shift in group centers is rotationally symmetric, with the COIs spaced about 90° apart on roughly a 1-mil radius.* It can thus be argued that rotation of the barrel's centerline is the cause of the COI rotation.

Some indication of the sensitivity of projectile jump (and hence COI) to centerline curvature may be gained by examining the rotated tube test on a component basis. The horizontal and vertical centerline components of tube 84 are displayed in Figure 2, corresponding to the COI at 0° in Figure 1. Rotating the barrel in 90° increments changes the horizontal and vertical components into the vertical and horizontal components, respectively, with a sign change, where appropriate, to remain consistent with the gunner's coordinate system (i.e., left—negative, up—positive). For example, the negative of the vertical centerline at 0° becomes the horizontal centerline at 270°, Figure 3.

As can be seen in Figure 3, the horizontal centerlines at 0° and 270° have some features in common. Their profiles are sinusoidal in nature, resembling roughly 1.5 cycles of a sine wave, with the "wavelength" of each nearly the same; and, as viewed from the chamber forward, both centerline components move right (positive deflection) and left (negative deflection) in the same progression. However, the two sinusoids differ from each other in being slightly out of phase, resulting in slightly different muzzle exit conditions; and, one profile is biased toward the right (i.e., positive centerline excursions are larger than negative ones), whereas, the other is biased toward the left.

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* Even though the prefiring aim point was at the horizontal and vertical origin for each orientation in Figure 1, the center of COI symmetry appears to be shifted vertically about 0.5 mil. This shift in the center of symmetry above the prefiring aim point might be caused by a positive shift in muzzle pointing angle at the time of shot exit. Such a change in muzzle angle during inbore travel could result from the upward barrel rotation caused by the torquing action of the center of gravity offset in the recoiling breech assembly.

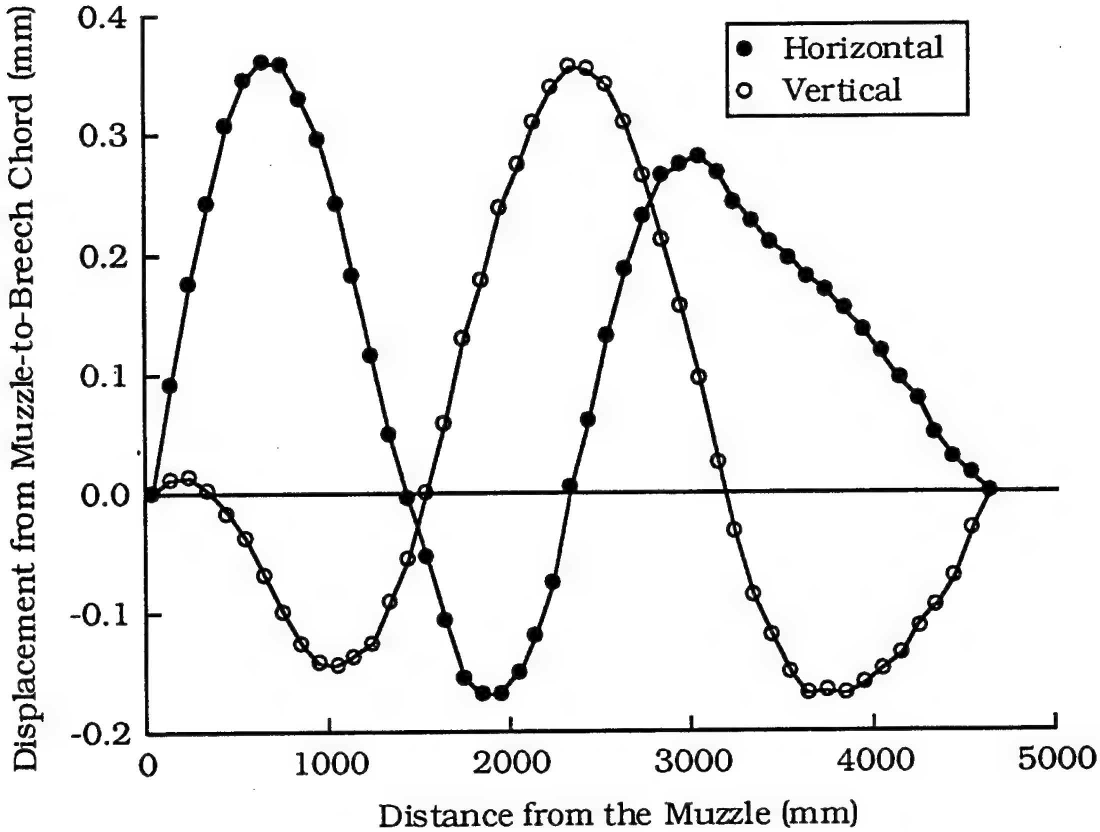

Figure 2. Horizontal and vertical centerline profiles of M256 (ser.no. 84) in rotated tube test (at 0° orientation).

How will the similarities and differences noted in Figure 3 influence the horizontal fall of shot? When the near 1.5-cycle horizontal centerlines are reversed, quite different changes in the COI occur. For example, in going from 0° to 180°, the horizontal component of the COI in Figure 1 changes from roughly 0.4 mil at 0° to -0.1 mil at 180°, a 0.5-mil change. However, in going from 270° to 90°, the change in the horizontal COI is from -1.3 mils at 270° to 1.5 mils at 90°, nearly a 3-mil change. Interpretation of these results depends on how much the mount and occasion change affects the COI change with each rotation. For example, if we assume that the mount and occasion changes do not appreciably affect the COI, then the large difference between COI changes, viz., 3 mil vs. 0.5 mil, implies that projectile jump is sensitive to the magnitude and location of each oscillation, even if the number of oscillations is nearly identical (Figure 3). On the other hand, if the mount and occasion change can significantly influence the COI, then specific inferences about the effect of curvature on fall of shot are difficult to ascertain from the rotated tube test.

The significance of the COI-centerline test described here is that the centerline can be changed without remounting the barrel, thus, there is no doubt that the centerline is the sole contributor to the COI change.

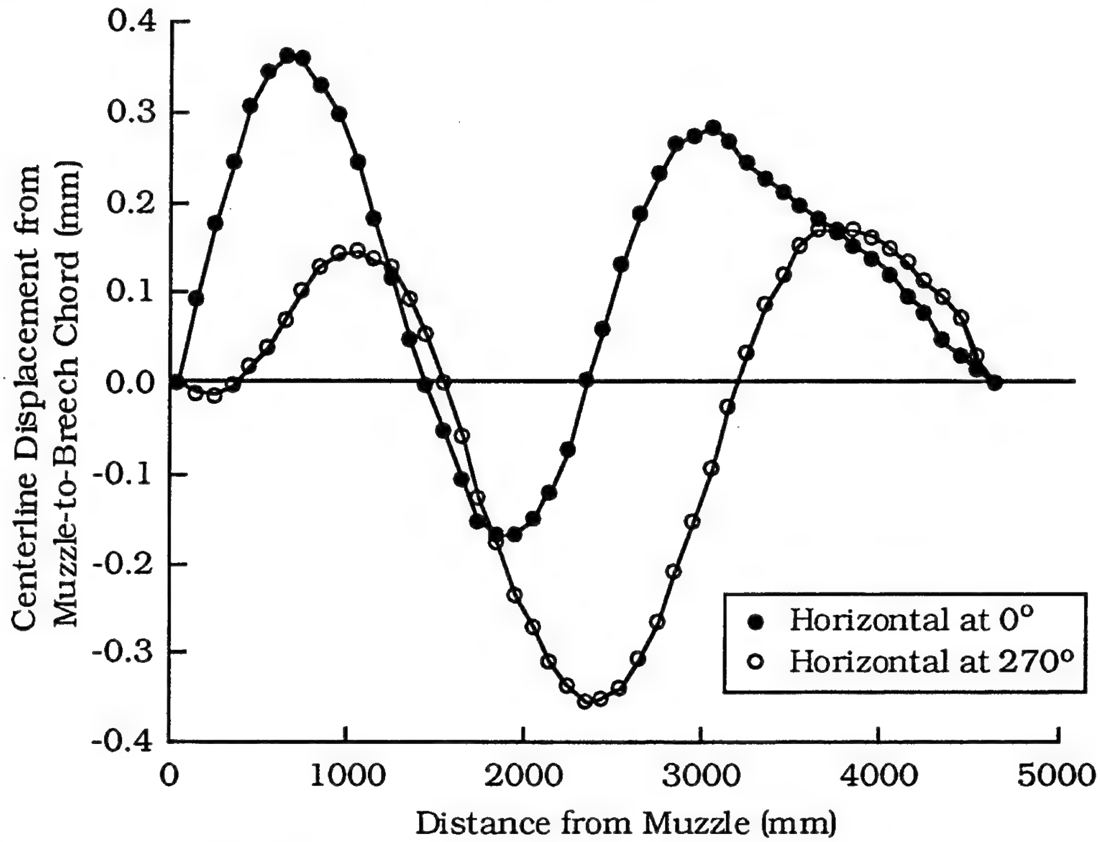

Figure 3. Comparison of horizontal centerline profiles at 0° and 270° orientations in rotated tube test.

2. CONTROLLING THE CENTERLINE

A series of heating pads was adhered to the outer wall of an M256 barrel (ser. no. 2971). A small hole in the center of each pad accommodated the placement of a thermocouple used to measure the barrel temperature. The temperature of the barrel under each pad could be stabilized by automatic or manual control of the heating pad's on-off switch. Hence, it was possible to control cross-barrel temperature differences (CBTDs), and thus control differential thermal expansion across the tube, so that the barrel centerline could be changed as needed. A detailed description of the experimental setup and validation of the thermal bend control can be found in Bundy (1996).

This being the first firing test of a thermally controlled barrel, it was deemed sensible to limit the analysis to the horizontal plane only, where fewer factors influence gun dynamics. That is, in the vertical plane, the unidirectional effects of gravity on the barrel and projectile add complexity to the analysis of gun dynamics. Furthermore, it is known (e.g., Erline and Kregel 1988) that the effects of the breech center-of-gravity (cg) offset will overshadow the effects of centerline curvature on vertical plane gun dynamics.

To further simplify the experiment, only a simple bow shape, or half-sine wave curvature, to the left and right, as well as a near-straight centerline were chosen for analysis. It should be noted, however, that some (Schmidt, et al. 1990) think barrels with multiple changes in curvature, like that shown in Figure 2, produce greater jump than simple bow-shaped barrels.

The magnitude of the bow shape was varied twice in each direction to give a total of five trial cases, which are distinguished as bow left, bow right, large bow left, large bow right, and near straight in the horizontal centerline plots of Figure 4. How do these five trial cases relate to the natural curvatures found in the general population of tube centerlines? In the dispersion study of Wilkerson (1995), 20 M256 tubes were examined. Of these 20, 15 (75%) had a simple bow shape in either the horizontal or vertical plane, much like "2971." Ten of the 20 barrels (50%) had bow shapes that were greater in magnitude than that of 2971, but smaller in magnitude than the bow-left and bow-right curvatures in Fig. 3. Five of the 20 (25%) had bows that were as large as the bow-left/right curvatures, but smaller than the large bow-left/right curvatures. As a final note, a simple bow shape is the first natural mode of vibration for a barrel; hence, such a shape may dominate the centerline curvature in barrels firing on the move over "bumpy" terrain.

Bear in mind, the centerline plots of Figure 4 are not based on actual measurements, which are not possible using an optically based centerline measuring instrument in an above-ambient temperature bore. Rather, they are based on theoretical predictions using the thermal bend model of Bundy (1993). Past testing has shown (Bundy 1996), however, that there is good agreement between the thermal bend model and obtainable experimental measurements.

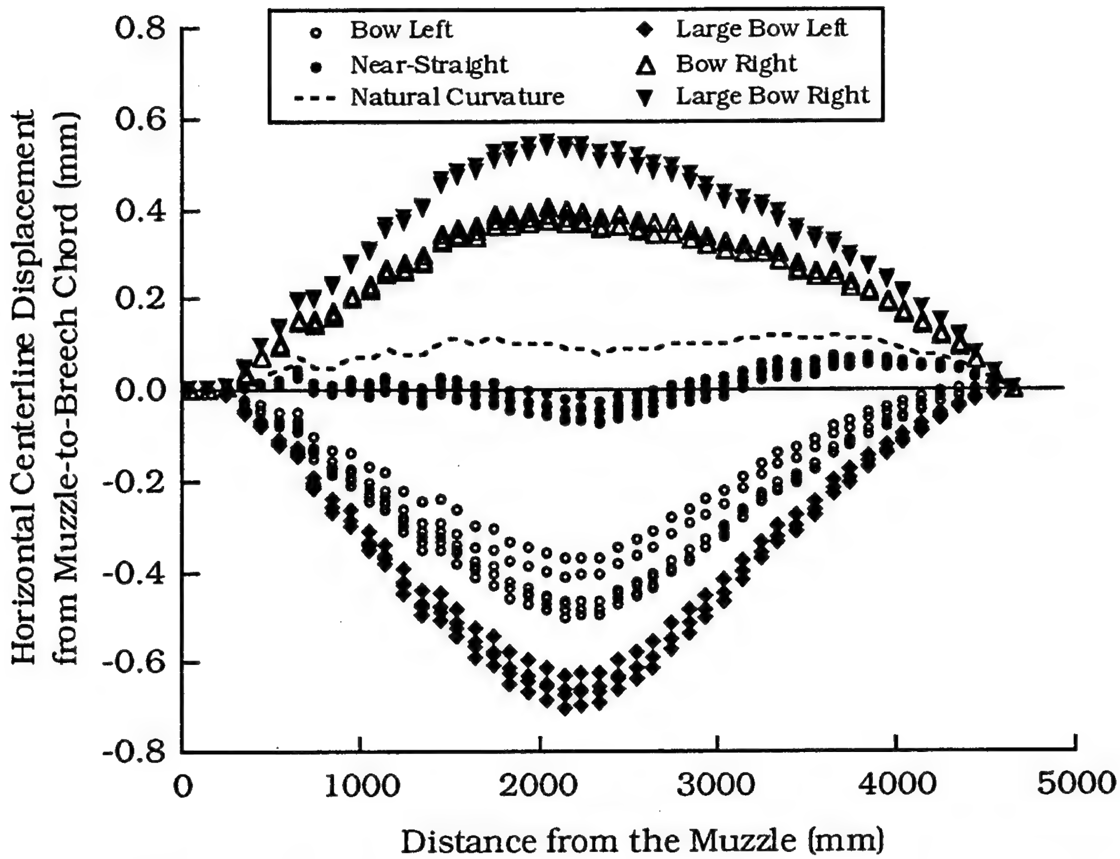

Figure 4. Manufactured and heating-pad-induced horizontal centerline curvatures prior to firing M256 (ser. no. 2971).

There are several centerline plots drawn in Figure 4 for each of the five general curvature cases. For example, there are five distinctly different plots for the bow-left case. Each plot represents the centerline profile when a round was fired. The small variation in plots for the same case attests to the fact that it was not possible to maintain exact control over the cross-barrel temperature differences (CBTDs), which affect thermal bend. In actuality, there were six rounds fired for the bow-left case, with two plots overlaying each other. However, regardless of the number of plots that can be distinguished, there were at least four rounds fired for each general curvature case.

The ambient temperature during the 5-day testing period never exceeded 20° C. The barrel temperature would, of course, rise above ambient after firing. To maintain a consistent set of starting conditions for each firing, all heating pads were set to maintain a minimum barrel temperature of 25° C. A large-

volume air pump was used to blow ambient air through the barrel from the breech to the muzzle after each round; this expedited the return of the barrel to the 25° C minimum starting condition. Once the starting condition was reached, the blower was removed and manual control of specific heating pads was used to raise the barrel temperature above the 25° C minimum, in accordance with the temperature distribution required to create a given centerline profile. For example, the bow-left profile was created by raising three consecutive heating pads on the gunner's left of the barrel to 31° C, 39° C, and 31° C, as indicated in the schematic of Figure 5, while all other heating pads maintained the 25° C minimum barrel temperature. Actually, Figure 5 plots the right-minus-left CBTDs, rather than the absolute temperatures, since it is temperature difference that determines the amount of thermal bend that will take place.

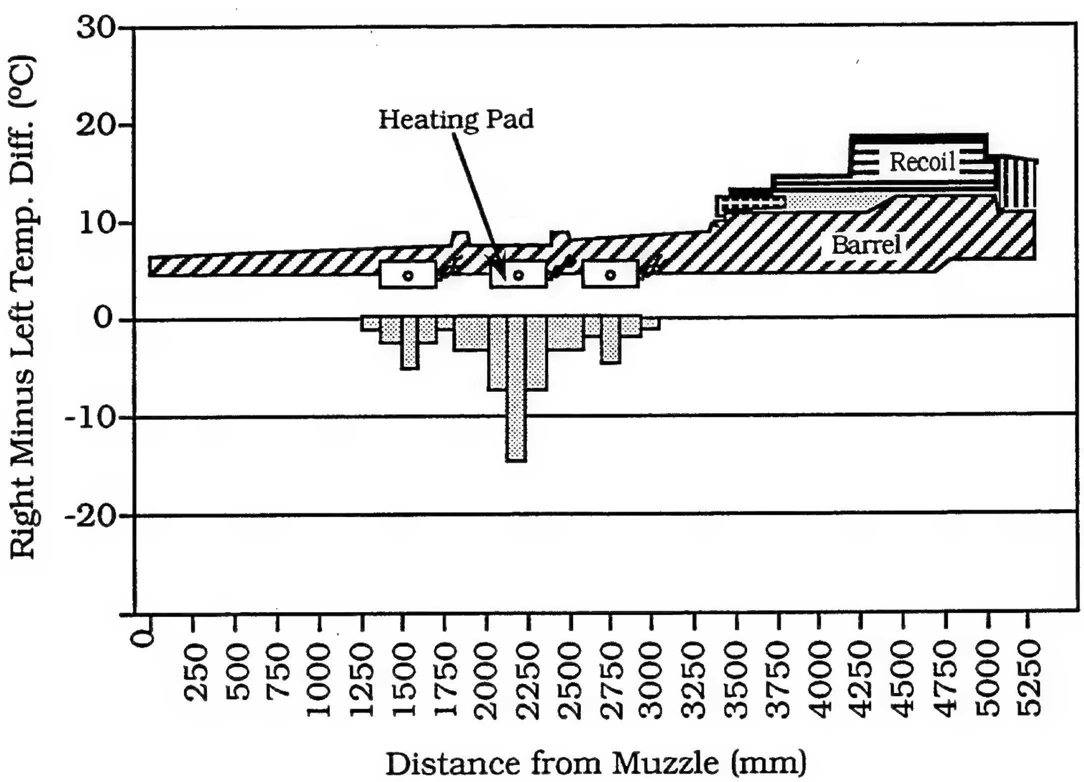

Figure 5. CBTD profile needed to induce bow-left configuration of Figure 4.

3. MEASURING THE COI

In total, 29 rounds of same-lot M865 target practice, cone-stabilized, discarding-sabot, training (TPCSDS-T) ammunition were used in this test. To reduce the dependence of occasion-to-occasion differences on the results, the firings were sequenced so that a round was fired with the centerline bowed to the left; then a near-straight centerline was fired; and then a round was fired with the centerline bowed to the right. This left-straight-right pattern was repeated, with, on average, a round being fired every 30–60 min. (Although the centerline could be changed in 5–10 min, a period of 20–30 min was required to bring the barrel back down to the 25° C starting condition, using the forced air blower.) Six test rounds were fired per day.

A spotter round was fired at the beginning of each day to "set" the gun, which biases clearances and tolerances in the gun-mount system in one direction. These biases are, for the most part, maintained during the course of subsequent firings but can "relax" if the period between rounds is excessive (e.g. 24 hours). To gauge the relative motion of the mount, and therefore the breech pointing angle, a 20-power telescope (a so-called Wye scope) was placed in a special cradle that was rigidly attached to the outside wall of the recoil cylinder. The Wye scope was used to read a grid board located 103 m downrange. The accuracy of this reading was considered to be 0.01 mil. Figure 6 shows, as implicated, that the largest change in breech angle occurs after the spotter rounds. Thereafter, the mount remained fairly stable. This mount, located at the U.S. Army Research Laboratory's Transonic Range, held tube 2971 in an M1A1 recoil that was attached to an Aberdeen Proving Ground (APG) "yoke" through an APG "adapter" plate. The APG yoke was affixed to the recoil system (equilibrator, trunnions, and pedestal) of an 8-in M110 howitzer. However, the recoil system was not vehicle mounted; rather, it was rigidly bolted to a concrete ground slab. Based on historical Wye scope data (from past firing tests), this M110 "pedestal mount" was as stable as the much heavier adjustable span mounts used by the U.S. Army Aberdeen Test Center at their "main front" firing sites.

The pointing angle of the muzzle end of the gun could be changed by altering the breech angle, or it could be changed by thermal distortion of the barrel between the breech and the muzzle. The muzzle angle was measured

using a so-called APG muzzle scope. The reading accuracy of the APG scope is considered to be 0.05–0.10 mil.

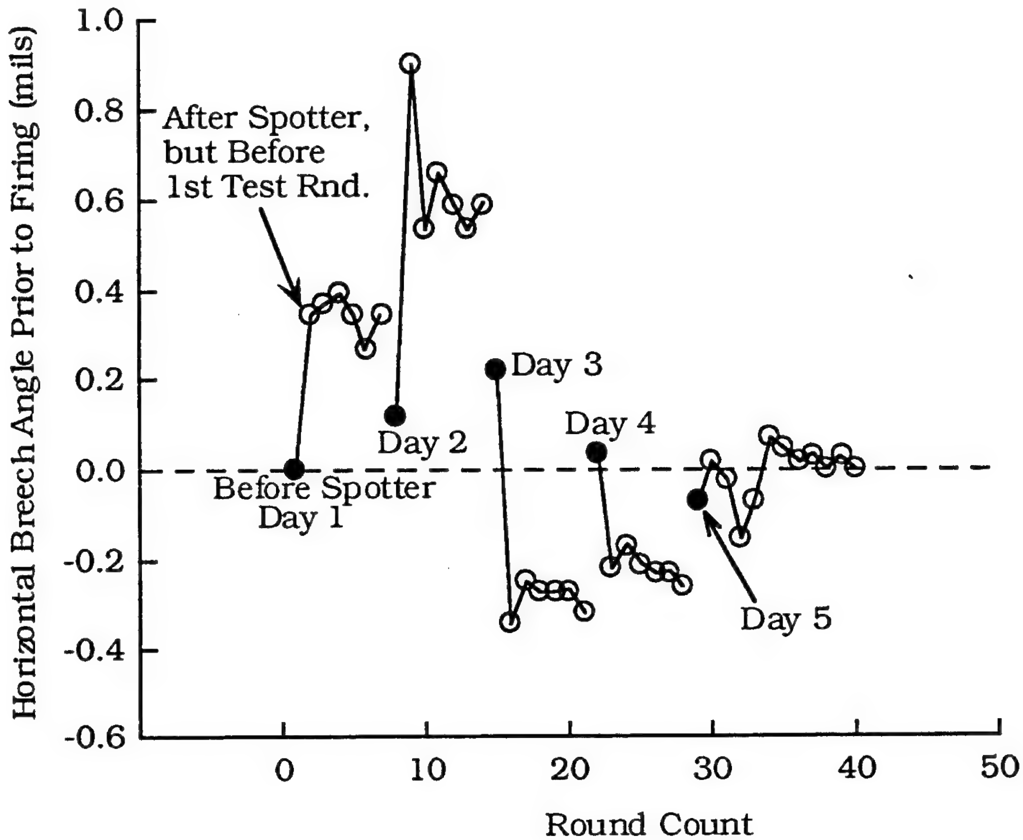

Figure 6. Change in horizontal breech pointing angle during 5-day firing period.

In addition to the baseline breech scope measurement, a baseline muzzle scope reading was taken before each day's firings. In fact, prior to taking these baseline measurements, the azimuth and elevation of the gun mount was adjusted so that the collimated APG scope was pointing at a painted cross on a downrange target cloth (super-elevation to compensate for gravity drop was then added). As discussed, however, firing the pretest spotter round would normally move the mount so that the gravity-corrected pointing angle of the muzzle scope after the spotter round, and before the first test round, was not usually directed exactly at the target cross. Rather than move the mount again (to align the muzzle angle with the cross), and risk having to fire another spotter round to ensure the mount was once again set in place, the post-spotter-round readings of the breech and muzzle scopes were taken as the pretest-round pointing angles.

After the CBTD pattern needed to create a specific curvature (one of the five general shapes shown in Figure 4) was established, a check of the breech and muzzle pointing angle was made. This check helped ensure that the proper curvature was indeed present prior to firing a round. For example, Figure 7 shows a typical day's record (day 3) of the muzzle-minus-breech pointing angles prior to firing (zero represents the unheated barrel). It can be seen that the measurements were close to those expected from thermal bend modeling for each of the three configurations. The end-to-end thermal bend for the bow-left and bow-right cases are symmetric about the near-straight case, as expected. However, the near-straight case required a small thermal bend to the gunner's left in order to compensate for "2971's" small natural bend to the right (see Figure 4). This resulted in the small positive offset seen in Figure 7 for the near-straight case.

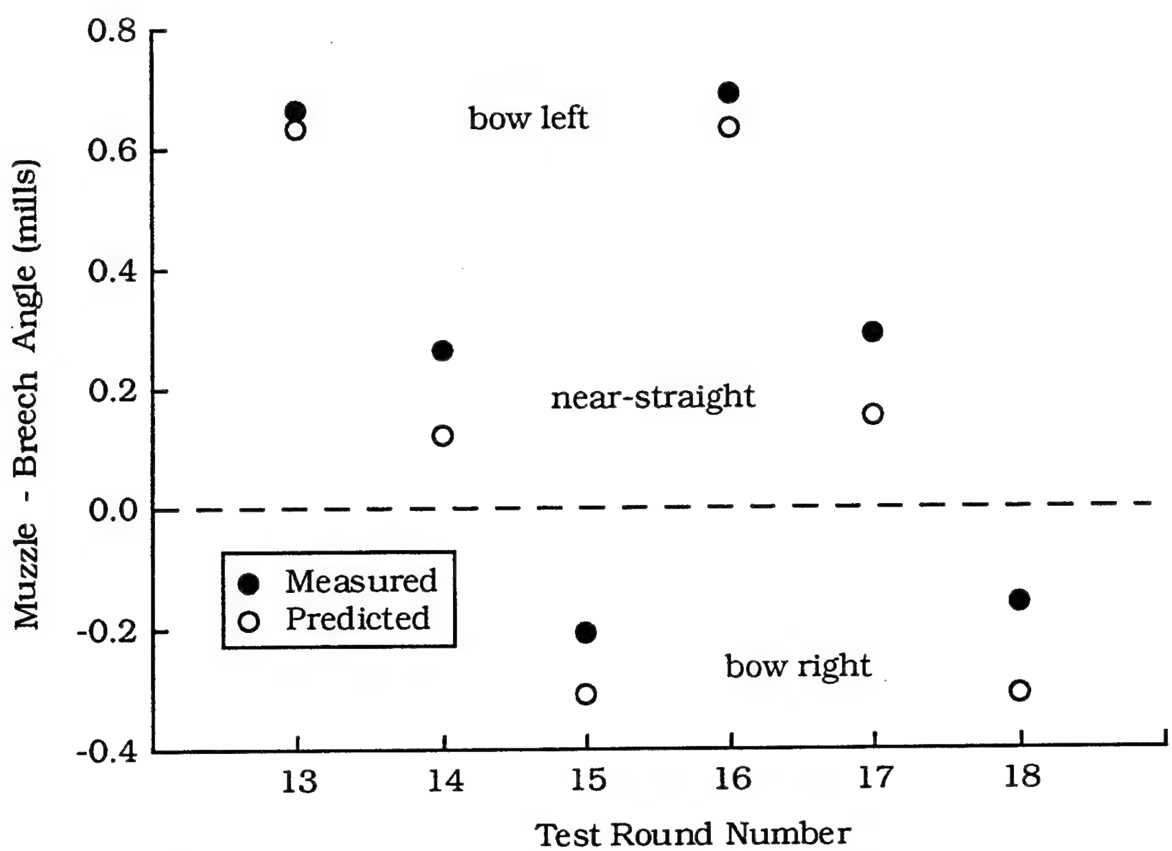

Figure 7. CBTD-induced change in the end-to-end thermal bend of the barrel, as measured by the muzzle-minus-breech pointing angle.

After firing each round, the target impact location was marked, and later measured relative to the initial (prespotter) aim point. The horizontal distance from the initial aim point, divided by the distance to the target (953 m), was used to convert the shot impact location into an angular deviation (in mils) off the original "line of fire." Having determined the prefiring muzzle pointing angle (relative to the initial aim point) and the shot impact angle for each test round, the two angles were differenced to establish the horizontal jump angle for each round. Finally, the mean horizontal jump angle was computed and defined as the COI for the group of rounds associated with each specific barrel curvature.

4. COMPARISON OF THE COIs WITH CENTERLINE CURVATURES

The first comparison is between the COIs and centerline curvatures of the bow-left, bow-right, and near-straight configurations. An illustration of the results is displayed in Figure 8. For the bow-left case, the horizontal COI falls 0.30 mil to the left of the muzzle pointing angle. Whereas, for the bow-right case, the horizontal COI falls only 0.02 mil to the left of the aim point. For the near-straight barrel, the COI lies in the middle of the bow-left and right result, viz., 0.14 mil to the left of the aim point. It can be seen from the schematic of Figure 8 that, relative to the near-straight case, inducing a left bow will move the muzzle to the right and the shot impacts to the left. Conversely, forming a right bow will move the muzzle to the left and the shot impacts to the right of the near-straight case.

When the barrel is distorted into the large bow-left configuration, the COI lies, surprisingly, at virtually the same location as the smaller bow-left firings—in this case, 0.29 mil to the left of the aim point, Figure 9. Similarly, the COI for the large bow-right firings lies at the same location as the smaller bow-right firings, viz., 0.02 mil to the left of the aim point.

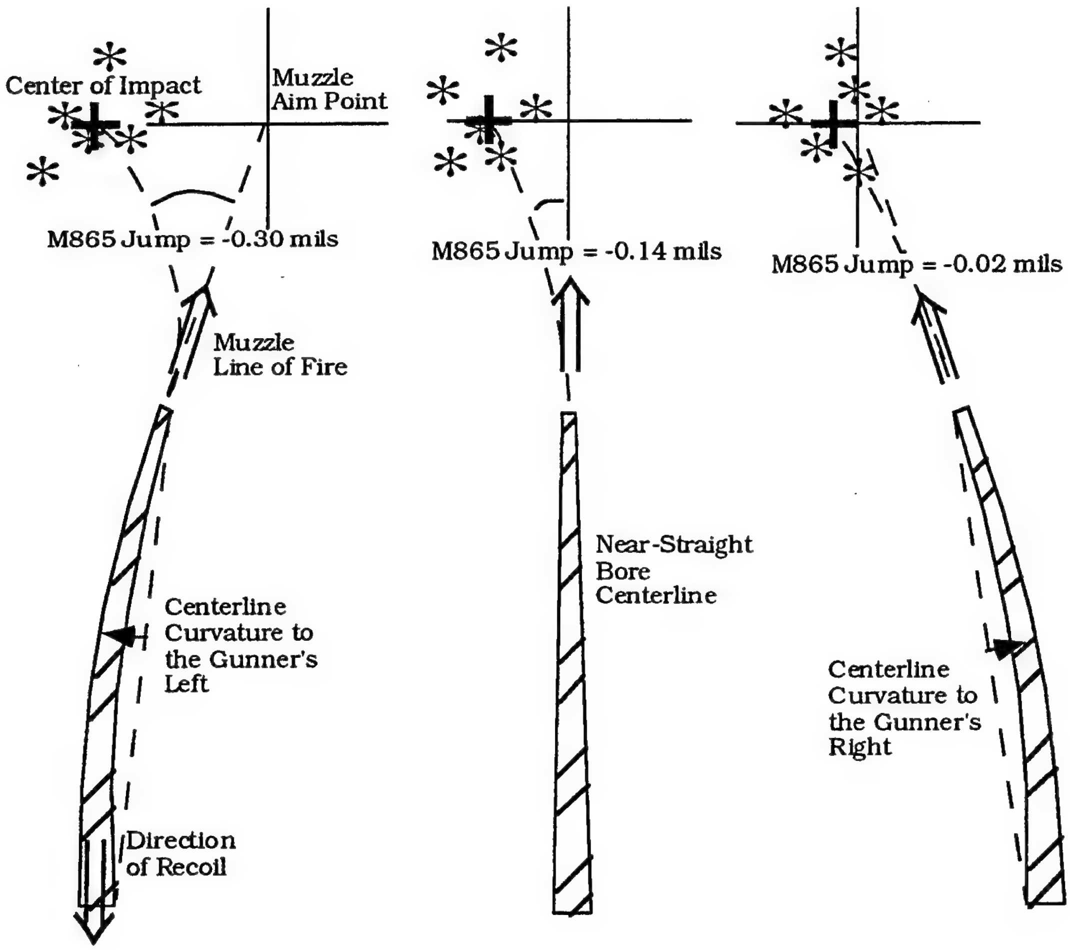

Figure 8. Illustration of M865 COI vs. centerline curvature (in the horizontal plane) for three of five bent barrel cases.

The results for all five firing configurations are summarized in Table 1. It should be noted that on day 1 only four of six test rounds were considered "good" data rounds, with no entries (Table 1) for the bow-right configuration. The exclusion of the bow-right trials was based on the fact that the CBTD patterns for these two rounds were not deemed sufficiently close to the bow-right configuration. Such a problem did not occur again during the course of firing, because control of the CBTDs was changed from automatic to manual after the first day. This provided better control over the repeatability of centerline curvatures for all configurations.

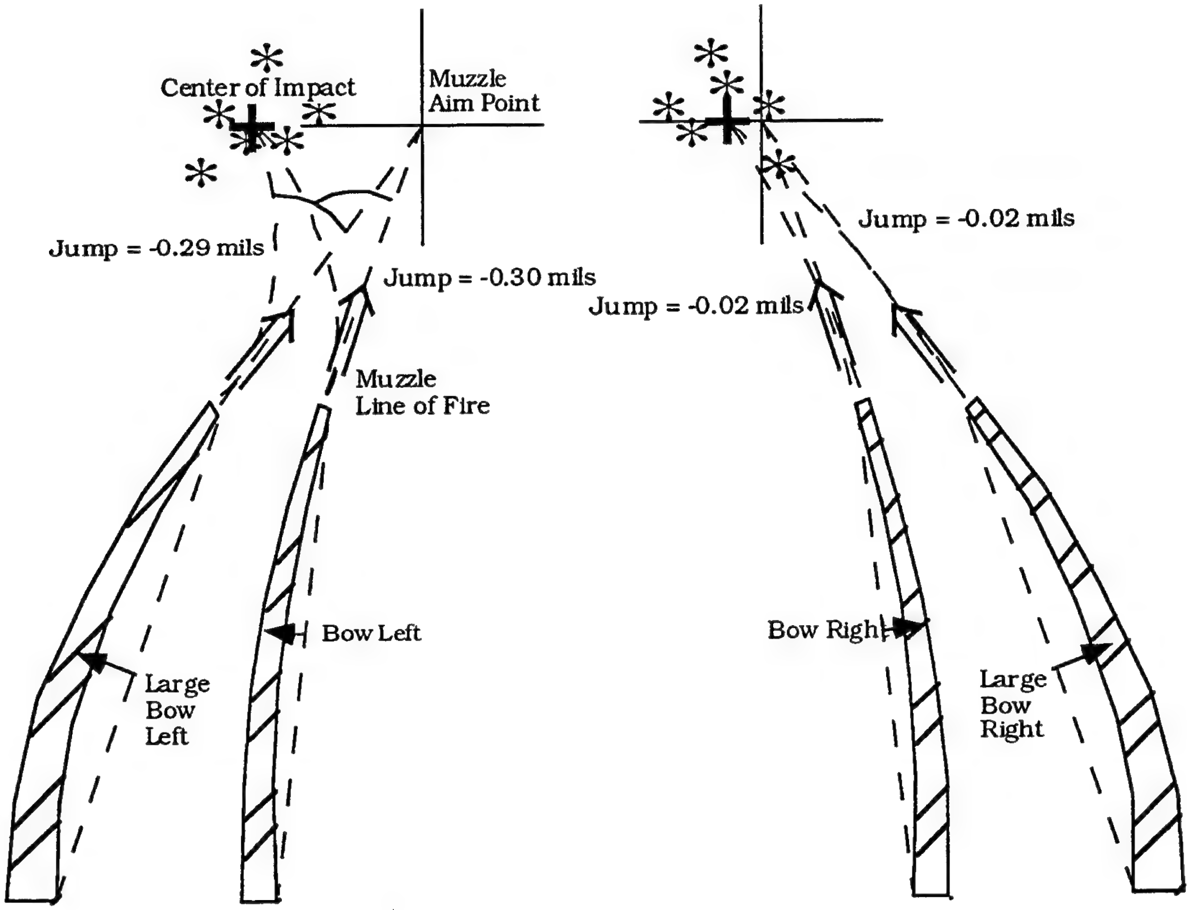

Figure 9. <u>M865 COI vs. centerline for larger-vs.-smaller barrel bends</u>.

Table 1. Horizontal Jump Values for Five Barrel Curvatures

	M865 Impact Angle Minus Muzzle Angle (mils)				
	Large Bow Left	Bow Left	Near Straight	Bow Right	Large Bow Right
Day 1		-0.285	-0.308		
		-0.347	-0.204		
Day 2		-0.164	-0.297	-0.049	
		-0.534	-0.067	-0.366	
Day 3		-0.177	-0.115	+0.180	
		-0.270	+0.130	+0.156	
Day 4	-0.345				+0.258
	-0.258				-0.141
	-0.366				+0.179
Day 5	-0.093				-0.136
	-0.262				-0.236
	-0.422				
Avg. Jump	-0.291	-0.296	-0.143	-0.020	-0.015
Std. Dev.	0.116	0.135	0.165	0.252	0.219

Though perhaps surprising to some, the observation that a centerline bowed to the left or right (with muzzle angle moved right or left, respectively) shoots rounds to the left or right, respectively, relative to a straighter centerline, has occurred before. In 1987, for example, during testing of a candidate thermal shroud for the M256 cannon (Bundy 1987), uneven cooling (due to a design failure in the shroud) caused the barrel to undergo a thermal bend to the gunner's left (bow left). As this occurred, the fall of shot also moved to the gunner's left. The correlation coefficient (r-value) between the bow-left thermal bend and the shift left in jump was highly significant, $|r| = 0.76$. A similar result occurred in a more recent test with a 25-mm chain gun (Garner et al. 1995); it was found that thermal distortion induced by uneven firing heat input caused the barrel to bow to the right and the shot impacts to move to the right.

It is worth noting that the 0.18-mil pooled standard deviation across the five groups of Table 1 is significantly lower ($P<0.005$) than the 0.29-mil horizontal dispersion obtained from the lot acceptance test (LAT), for this particular lot of M865s.** However, this is probably to be expected, since in this test, unlike the LAT, the centerline curvature, and hence gun dynamics, is virtually the same for every round fired in each group. For this reason, the pooled standard deviation from this test is probably more representative of the "true" horizontal dispersion than that obtained from the LAT. Moreover, it might be inferred from such a large decrease in dispersion that if barrel curvature was unwavering from round to round it could significantly improve the hit probability at longer ranges.

5. MODELING THE EFFECT

In an effort to gain an understanding of the results, a gun dynamics model—Rascal—was employed to model the projectile-barrel interaction for the five configurations. Operation of the Rascal code is described by Erline, Kregel, and Pantano (1990). Briefly, five input files are required: one file describes the projectile physical properties, one the interior ballistics for the projectile, one the barrel dimensions, one the bore centerline, and one the breech and mount

** LAT data provided by Albert Pomey, U.S. Army Armor School, Fort Knox, KY; statistical analysis provided by David Webb, US Army Research Laboratory, APG, MD.

parameters. Among its outputs, Rascal provides the displacement of the projectile cg above or below the original (prefiring) bore axis. Furthermore, Rascal gives (indirectly) the transverse velocity component of the projectile's cg relative to the original bore axis, and (directly) the angle and angular rate at which the projectile exits the muzzle.

The primary factors that influence projectile jump are accounted for in Equation 1, obtained, for example, from Lijewski (1982), for a slowly rolling symmetric missile.

$$\text{Horizontal Jump} = \frac{s_\perp}{S_\parallel} + \frac{\dot{s}_\perp}{v_\parallel} - \frac{I_\perp}{m\, d\, v_\parallel} \frac{C_{F_\alpha}}{C_{M_\alpha}} \dot{\alpha} + E_r \ , \tag{1}$$

where $s_\perp$ is the horizontal (transverse) distance of the projectile cg off the original line of fire as it enters free flight; $\dot{s}_\perp$ is the horizontal velocity of the cg as it enters free flight; $S_\parallel$ is the distance from the muzzle to the target; $v_\parallel$ is the projectile's (longitudinal) muzzle velocity; $I_\perp$ is the moment of inertia about the horizontal axis; m is the mass of the projectile; d is the diameter of the projectile; C_{F_α} is the lift force coefficient; C_{M_α} is the restoring moment coefficient; $\dot{\alpha}$ is the time rate of change of the horizontal angle of attack as it enters free flight; and E_r is the horizontal jump due to the Earth's rotation beneath the projectile (i.e., the Coriolis force).

The first two terms in Equation 1 are affected by the gun motion at shot exit and the sabot separation dynamics. The third term is the only term which involves aerodynamic forces and moments; it is the aerodynamic jump component of the total jump.

For this test (range location, distance, and type of round fired, M865), $S_\parallel$ = 953 m, $v_\parallel$ = 1704 m/s, $I_\perp$ = 0.033 kg·m^2, m = 2.72 kg, d = 0.038 m, C_{F_α} = 9.81, C_{M_α} = -18, and E_r = 0.03 mils (to the gunner's right).

Although $s_\perp$ is the horizontal distance off the line of fire after the projectile has transitioned through the sabot discard regime, the effects of sabot discard were not measured in this test. Thus, it is assumed that $s_\perp$ is the

value at muzzle exit, obtained from Rascal, which is so small as to be negligible in comparison to $S_{\parallel}$. Likewise, $\dot{s}_{\perp}$ and $\dot{\alpha}$ were not measured after sabot discard and are assumed to be the values at the muzzle, again, obtained from Rascal. Not knowing the effects of sabot discard on these variables is a weakness of the current analysis.

Without further elaboration, Equation 1 was used to predict the projectile jump outcomes listed in Table 2. Also shown in Table 2, for direct comparison, is a repetition of the measured mean jump values (COIs) given in Table 1. It is quite obvious that the predictions do not agree with the measurements.

Table 2. Rascal Jump Predictions for Five Barrel Curvatures

	M865 Average Horizontal Jump (COI)				
	Large Bow Left	Bow Left	Near Straight	Bow Right	Large Bow Right
Rascal Predicted COI	+1.20	+0.838	+0.023	-0.761	-1.03
Measured COI	-0.291	-0.296	-0.143	-0.020	-0.015

In general, the Rascal predictions call for jump to result in a projectile deflection to the gunner's right of the aim point, if the muzzle is bowed left, and a deflection to the left of the aim point, if the barrel is bowed right. The magnitude of the deflection is predicted to be nearly proportional to the magnitude of the bow. A small deflection to the right of center is predicted for the nearly straight tube.

On the other hand, all observed projectile deflections were to the left of the aim point. Furthermore, the magnitude of the deflections were far less than that predicted by Rascal, and, there was no connection between the magnitude of the barrel bend and the magnitude of the observed deflection.

It should be mentioned that a small torque, due to the slight offset (to the gunner's right) in the breech's horizontal cg relative to the bore axis was included in the Rascal computations of Table 2. However, this torque produced

only a minor deflection of the projectile to the gunner's left, -0.03 mils for all five cases, not enough to bring the predictions into agreement with the observations.

Even though the effects of sabot discard are not included in the calculations, it is not likely that they would remove the large discrepancy between the Rascal predictions and the measurements in Table 2. Other known deficiencies in the Rascal model would include: 1) the spring constants, which model the interaction between the projectile and the barrel, are based on static measurements and do not include the compressive effects of longitudinal acceleration; 2) Rascal considers the barrel support points to be the same in both the horizontal and vertical directions, which is not a physically accurate description; and 3) the model does not include the effects of "gun whip" due to recoil of a bowed barrel, but this is probably a relatively small term.

6. CONCLUSIONS

Controlled changes of the bore centerline with heating pads provide a means to isolate the effects of tube-to-tube variation on the fall of shot without entailing a mount or an occasion change. Five simple, nevertheless common, centerline profiles were examined. The shape changes were all made in the horizontal plane to avoid the complexities introduced by gravity and the large vertical cg offset of the breech.

It was found that same-lot M865 rounds fired through a nearly straight tube were grouped about a COI that was on the gunner's left of the prefiring muzzle aim point (-0.14 mil). When the bore centerline had a bow to the left, and the muzzle pointed to the right, the COI was to the left of the near-straight case (-0.30 mil from the aim point). When the centerline was bowed to the right, and the muzzle pointed to the left, the COI was to the right of the near-straight case (-0.02 mil from the aim point). However, a change in magnitude of the left and right bows did not change the COI. Overall, the average COI for all five cases was about -0.15 mil.

Assuming the M1A1 fleet has roughly the same number of right-bowed barrels as left, we might expect the fleet COI for M865s, which is +0.15 mil, would be close to our "five-barrel" average, -0.15 mil. The difference begs the

question of whether the mount used in our test biased the COIs to the left? In the test of Walbert and Petty (1985), it was found that COIs for the same tube mounted in different tanks varied by as much as 0.8 mil. Since the difference between our same-mount, five-tube COI and the fleet COI is only 0.3 mil, it seems plausible that the bias to the left could be mount related.

Regardless of what bias the mount may impart, the change in COIs between the bow-left and bow-right centerlines were on the same order of magnitude as the LAT-based ammunition dispersion. This demonstrates that tube-to-tube variability, even for simple shapes, can be a significant contributor to tank-to-tank variation in shot impacts. The results also inferred that holding a tube shape relatively constant dramatically reduces impact dispersion, which would greatly increase hit probabilities at longer ranges.

Thermal distortion of the barrel due to uneven firing heat input, vertically stratified cooling (e.g., thermal droop), or unidirectional solar heating, can cause a bow-like change in the bore centerline. If a muzzle reference system is used to correct for this type of distortion, it could degrade accuracy more than if no correction at all were made, since the change in jump was found here to be opposite in direction to the change in muzzle angle.

In an attempt to understand why the COIs behaved as they did with the change in centerline, a gun dynamics model, Rascal, was utilized. Rascal computed the projectile's muzzle exit conditions, which, in the absence of knowing the sabot discard disturbance, were taken to be the conditions for the projectile's entrance into free flight. The aerodynamic jump as well as the Coriolis force effects were included in computing the total horizontal jump expected for each centerline configuration. However, the calculated jump differed in magnitude and direction from that observed. The differences were so extreme that even inclusion of sabot discard would probably not bring the predictions and measurements into satisfactory agreement. Clearly, a more comprehensive model and basic research is needed to understand why the COI depends on centerline curvature in the way that it does.

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U.S. ARMY RESEARCH LABORATORY
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